DEVELOPMENT OF ACOUSTICAL METHODS

J. Bongrand and P. Lienard

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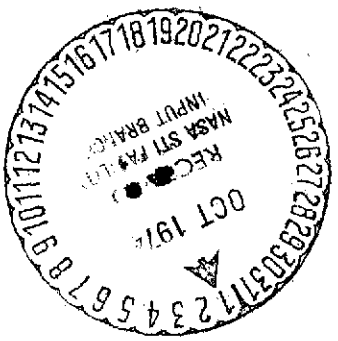

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16. Abstract

The already-existing installations described include the anechoic chamber of the Center for Testing of Propulsion Systems (CEPr), the ONERA combustion laboratory, wave propagation tubes for study of the noise generated by rotary machines and other small-scale purposes, the SNECMA soundproofed compressor test bench, and the large Modane S1 windttunnel. Installations being planned or currently under construction include the ONERA anechoic chamber with wind tunnel,ffor research on pipes, rotor fans, blown wings, etc., a new free-flow wind tunnel at the CEPr, and the acoustical metrology laboratories of the Toulouse Study and Research Center.

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Report of P. Lienard (ONERA) and J. Bongrand on the Development of Acoustical Methods (ISL Colloquium, May 14-16, 1974).

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Figs. 12 to 25. (Blueprints of the other planned installations are not currently available.)

1. Necessity for Special Experimental Methods /1*

Experimental studies on the sonic emissions produced by turbulence in gaseous flow call for the use of special installations which should combine the characteristics of acoustical test benches, wind tunnels and anechoic rooms.

Since a large number of parameters must be obtained and computations performed, fast methods must be available: real time analyzers, correlators and computers for management and acquisition to process and store the data obtained.

This discussion will include a brief description of existing test installations, not only those of ONERA [Office national d'études et de recherches aérospatiales; National Office of Aerospace Study and Research], but also throughout France (since there is a frequent exchange of experimental methods and results). Following this, plans for new installations will be discussed so that these can be compared with those of our foreign colleagues; we will be happy to hear your opinions on this subject.

2. Installations Existing in France

2.1. The Anechoic Chamber of the Center for Testing of Propulsion Systems (CEPr)

Put into operation in 1967 for jet noise studies on models at a scale of about 1/10, this anechoic chamber was the first specialized installation of its kind. It is used continually by SNECMA and ONERA and occasionally by airplane designers.

The special characteristics of the anechoic chamber consist /2 in its soundproofing, air circulation system and measurement device.

*Numbers in the margin indicate pagination in the foreign text.

2.1.1. General Configuration and Soundproofing

The chamber is a parallelopipedal enclosure with internal dimensions of 14 x 10 x 4.5 m. The walls have been soundproofed for two purposes:

-- to protect the test chamber from noise and vibrations of external origin. Thus a sound level of 57ndB has been measured inside the chamber when the outside level was 106 dB.

-- to absorb the noise emitted by the source under study, that is, to eliminate reflection in order to recreate the sound field which this source would produce if it were located in the open air, at a distance from any obstacles. The error duedto reflection is no more than 1 dB at 6 m from the model.

In order to obtain these results, the chamber is double-walled: the outer walls are composed of cementt50 cm thick. The inner chamber rests on the preceding structure with an intermediate layer of cork, and has a cement floor and brick walls. The inner lining notably includes an air gap (resonator) and glass wool dihedrals which cover the ceiling, walls and floor.

The only openings are:

-- the entry door, consisting of iron, wood and glass wool. This weighs 7 tons and slides on rails. Joints are used to ensure airtight closure.

Thethe openings of the air circulation system, which will now be described.

2.1.2. Air Circulation System

The anechoic chamber serves primarily for measurement of jet

noise in pipes. Primary and secondary air intakes have thus been provided. The compressors used are able to furnish air at pressures as high as 8 bars, for a total maximum flow rate of 6 kg/sec, or 3.5 bars for 20 kg/sec. A propane-burning combustion chamber makes it possible to obtain generating temperatures as high as 1,350°K.

The noise transmitted by these pipes, which is much less than that of the jets, may be a disadvantage in some cases. A means of disconnecting the pipes is provided for cases when no airflow is necessary.

The gas outlet is a soundproofed pipe (perforated sheet metal and glass wool).

A dilution airflow makes it possible to cool the chamber and to obtain uniform inside temperature and humidity, facilitating atmospheric absorption computations. This air enters through the ceiling, after passing through various bends and baffles for sound damping. The jet in the pipe draws the air in by induction.

2.1.3. Sound Measurement

A microphone is placed on a boom which slides along a circular rail affixed to the ceiling of the chamber. In this way it is possible to measure the sound field at any point located within a cylinder with a radius of 6 m and a height of 3.5 m, for an azimuth of between 15° and 165° in relation to the direction of the jet.

A spectral analysis system permits frequency analysis of the sound spectrum from 200 Hz to 100 kHz.

The results obtained in this way undergo various processing

operations in real and deferred time by means of a completely automatic measurement chain. A graphic recorder furnishes the corresponding curves in real time.

Fig. 1. Photograph of outside of laboratory. The center area is the chamber itself, while above is the opening for the secondary air intake. The compressed air and fuel intake is hidden by the building. Combustion gases exit from the tube at right. /2

Fig. 2. Elevated cross-section of anechoic chamber. Center: a combustion jet. Above: secondary air intake. Right: the outlet noise suppressor.

Fig. 3. Cross-section. The secondary air intake circuit, the hexagonal bellmouth of the outlet noise suppressor and the measurement room may be seen.

Fig. 4. Inside view. Sound-absorbing coating consisting of fiberglass wedges. In the center, a pipe undergoing testing.

2.2. ONERA Combustion Laboratory

The research on hot jet turbulence described by Mr. Pérulli [2,3] was performed in a combustion test laboratory, permitting all the necessary aerothermodynamic measurements, as well as development of methods of investigation (infrared radiation, laser strioscopy, velocimetry, etc.).

Fig. 5 is an inside view of this laboratory. This is not an anechoic chamber, but a testing room which has been lined for sound correction. Thus the sound measurements are only comparative controls; precise sound measurements are performed in the anechoic chamber of the CEPr.

2.3. Wave Propagation Tubes

The noise generated by rotary machines, the propagation of sound waves in conduits, and the effects of absorption by walls and flow speed (including its fluctuations) are studied in extremely simple installations whose sole purpose is to test methods and to develop measuring equipment subsequently to be used on actual machines.

Fig. 6 is a diagram of a cylindrical tube in which microphones are able to explore the sound field along three coordinates: longitudinal z (slide following a generatrix of the cylinder), angular θ (rotating ferrule) and axial r (rod passing through the cylinder). A fixed microphone gives a phase reference. /3

This tube, formed of several fixed sheet metal sections, measures 60 cm in diameter and 4 m in length. At one end there is a six-bladed fan capable of turning at up to 4000 rpm. The maximum average wind speed in the tube is 20 m/sec. A tube section may be replaced by an internally absorbing component, for a acoustical study of perforated walls, for example.

Fig. 7 is a photograph of the tube. Primarily to be noted are the air intake bellmouth and the measuring equipment (filters, correlators). The fan is at the other end.(in the other room). The air suction and blowing are in separate areas.

Fig. 8 shows a movable microphone mounted on a radially sliding boom and on a rotating ferrule; this allows for testing along the coordinates r and θ.

Another tube, composed of plastic, has loudspeakers at its end powered with adjustable phase lags. This makes it possible to produce rotating acoustical modes without airflow [4].

2,4. The SNECMA Soundproofed Compressor Test Bench

Compressor noise studies are subsequently carried out by SNECMA on a test bench surrounded by a makeshift anechoic chamber; the part of this chamber involved in the test (rotor in its conduit) is separated acoustically from the drive motor and the other part of the conduit. In studying both the ONERA tube and the SNECMA conduit, the air circulation can be sent in either direction (upstream or downstream) by reversing the rotor.

Fig. 9 shows the layout of this test bench. The sound measurement area is bounded by walls lined with plastic foam. The sound field is explored by means of a microphone moving on a rotating arm (coordinates r, θ). /4

Fig. 10 is a photograph of the inside of this room. The fan inlet is at right. A microphone holder may be seen at left.

2.5. Use of Wind Tunnels

In 1970 an attempt was made to measure helicopter noise in the large Modane wind tunnel [5] without any modification of this wind tunnel. The measurements are known to have been disturbed by the noise of the wind tunnel fan and reverberations from the walls. During these tests there was in addition the noise of the motor used to drive the rotor.

However, it was possible to obtain a few results on part of the sound spectrum of the rotor relative to variations with the profile, the peripheral speed, etc.

Fig. 11 shows the outside of the S1 Modane wind tunnel. This wind tunnel, which is able to reach M = 1 in an airflow 8 m in diameter, receives its power (75,000 kW) from a waterfall, which, by means of Pelton wheels, directly activates the shafts of the

fan.

Fig. 12: layout of wind tunnel. The measurement duct is mounted on a carrier (weighing 400 tons). Several carriers are available, making it possible to prepare new setups while a test is in progress.

In measurement of helicopter noise, the microphones were placed in the plenum chamber and in the duct, close to the rotor.

3. Installations in the Planning or Construction Stages

3.1. The Planned ONERA Anechoic Chamber with Wind Tunnel

The quantity of acoustical research on engine noise (jets or rotary machines) and flow interaction (double flow, blown wings) is increasing tremendously, and earlier installations have quickly been found to be inadequate.

With the exception of the anechoic chamber of the Center for Testing of Propulsion Systems, which was specially designed for acoustical research, these installations are only fairly makeshift assemblies or modifications of previous equipment for other purposes. The anechoic chamber of the CEPr is thus in tremendous demand, and the program predicted for the future has appeared to justify planning two specific additional installations, one at the CEPr and the other at ONERA. These three assemblies will have complementary characteristics and will also complement already existing anechoic chambers or those planned by various organizations. /5

The purpose of the ONERA anechoic chamber is, first, to permit research by the Office itself under a long-term program, and second, to supply engine designers (SNECMA, Turbomeca), cell designers (SNIAS, Dassault-Breguet) or governmental organizations

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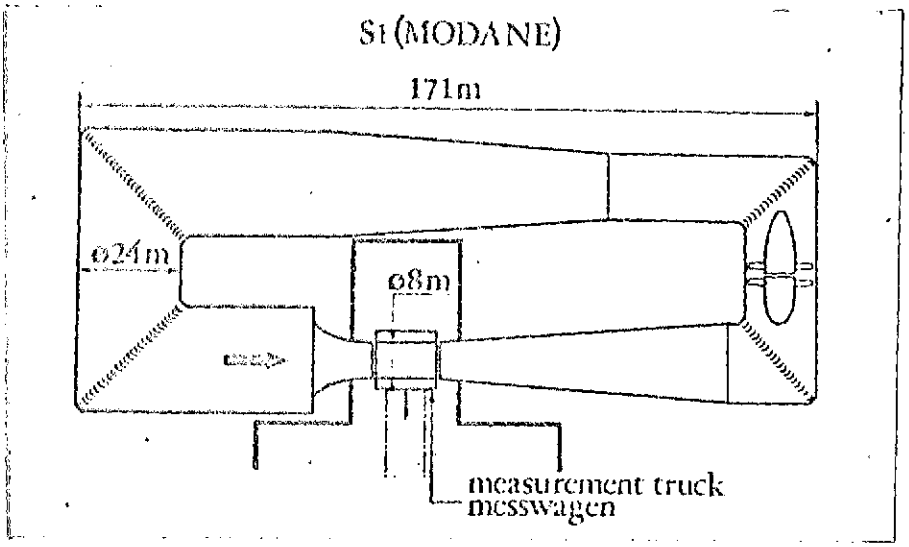

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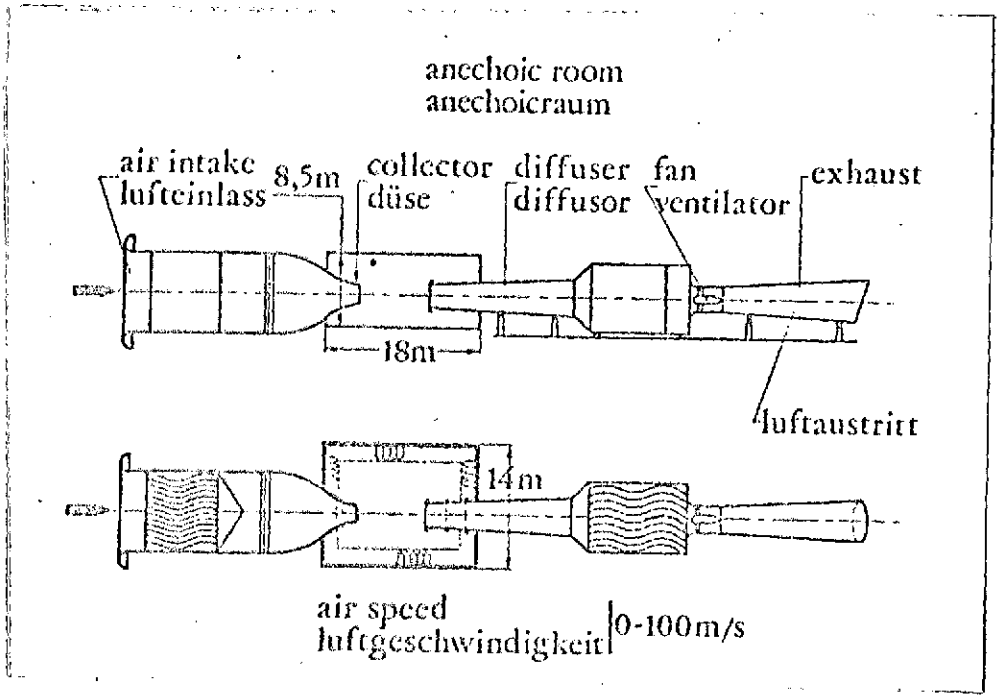

Fig. 13.

(DRME, STAé, SGAC) with test methods for research and development programs on pipes, rotor fans, blown wings, etc.

Fig. 13 shows the overall layout of this installation. This is basically a combination of a conventional anechoic chamber of large dimensions (18 x 15 x 8.5 m) with a free-flow wind tunnel passing through it; the latter permits various configurations through the use of fixed air manifolds or recovery intakes, giving various cross-sections and various windspeeds from 0 to 100 m/sec.

The entry noise suppressor is designed, not to stop outside noise, since this is slight and the noise levels studied inside the chamber are high, but to preclude disturbance of neighboring areas by this noise.

The purpose of the exit noise suppressor is to eliminate noise from the fan in the chamber.

Fig. 14. The inside lining of the room will be conventional. The cutoff frequency provided (absorption 99%) will be 125 Hz. Rapid disassembly of absorbing elements on the floor will make it possible to re-establish a reflecting surface like the cemented area of an airport. This disconnection will also permit assembly and disassembly of some types of large heavy models and instrument mountings.

Fig. 15 is a cross-section of the room. Two mobile overhead cranes, one on the outside and the other on the inside, two carriers and a wide door moving piston-wise will permit handling and storage of the air manifolds and recovery intakes. While measurements are being made, the overhead crane will be placed in a recess closed off by sound-absorbing panels. /6

With the two air openings more or less closed, this installa-

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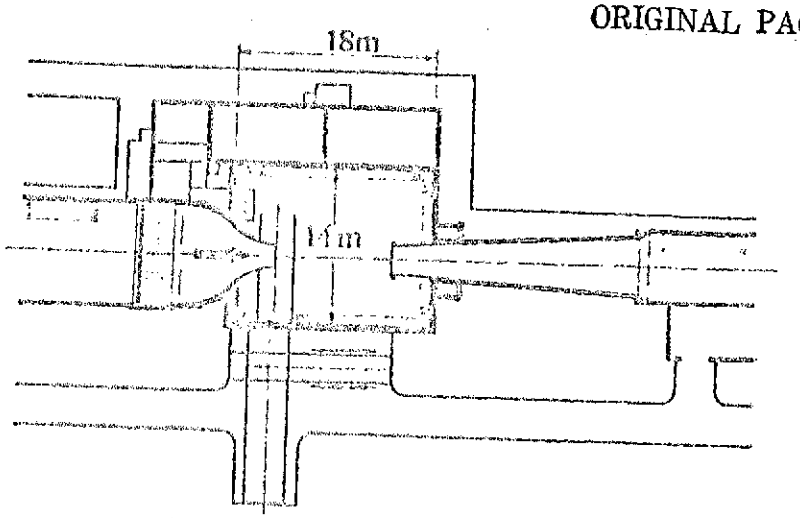

Fig. 14.

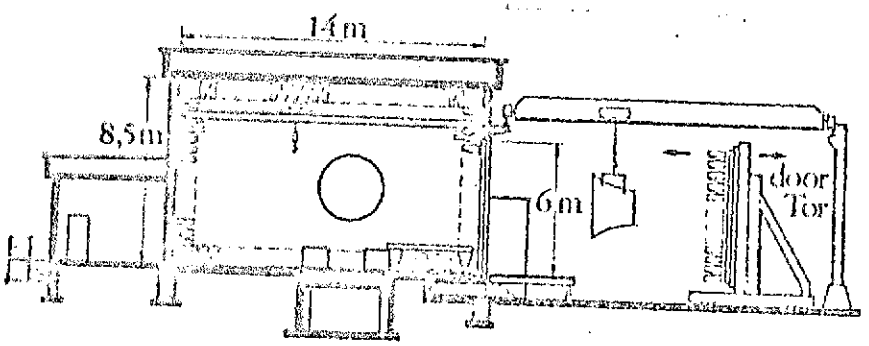

Fig. 15.

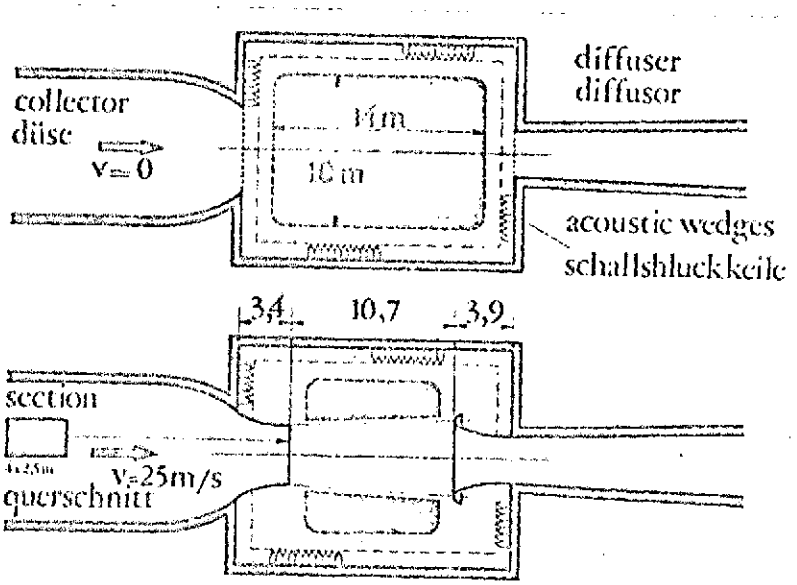

Fig. 16.

tion becomes a vast conventional anechoic room in which the volume available for sound measurement is 14 x 11 x 4.5 m, shown at the top of Fig. 16.

A large-cross-section converging duct (lower part of Fig. 16) leaves a rectangular free flow of 4 x 2.5 m with a maximum speed of 25 m/sec. This is suitable for the study of rotors or wing elements.

Fig. 17 shows two other planned configurations:

-- a flow 3 m in diameter, permitting a speed of 40 m/sec;

-- a flow 1.6 m in diameter, making it possible to reach a speed of 100 m/sec so as to simulate the take-off speeds of the fastest airplanes.

The space available for sound measurement obviously decreases as the distance between air manifold and air recovery intake is narrowed.

The supply of fuel and compressed air will be ensured by the existing and nearly completed installations of the aerothermodynamics Laboratories of the Energy Administration (compressed air flow of 10 kg/sec at 14 bars).

Local additions (shown in Fig. 18) will include control and observation posts and the equipment for acquisition and processing of measurements, connected with an existing central measurement computer which will be expanded, as well as with the Computation Center.

The methods for analyzing and processing the signals characteristic of this installation will be analogous to those already

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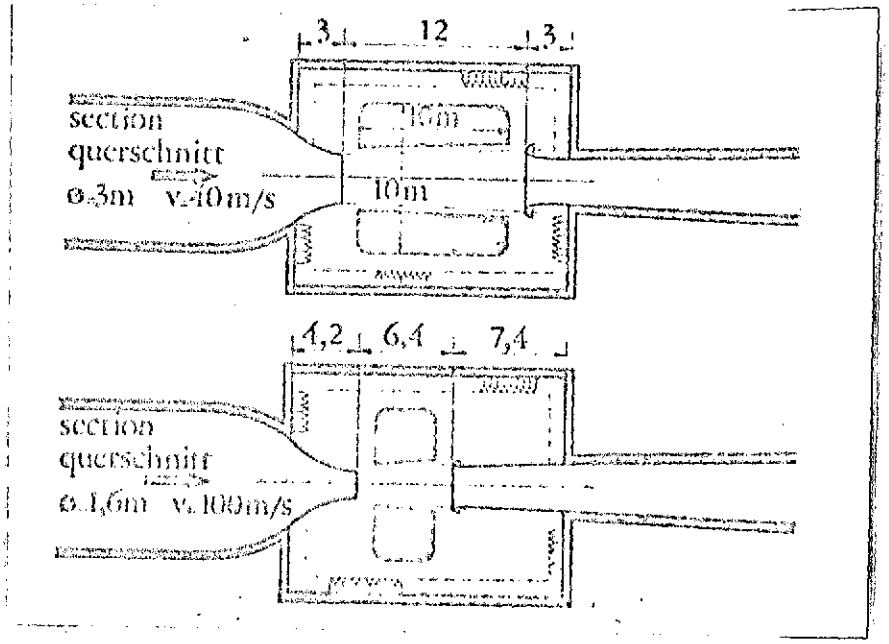

Fig. 17.

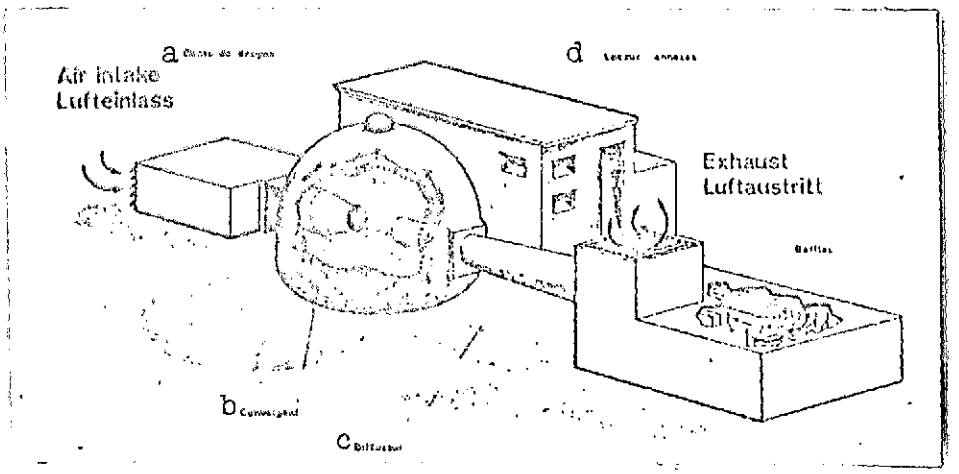

Fig. 18.

Key: a. "Dragon's teeth,"
b. Converging duct,
c. Diffuser,
d. Local additions.

described, [2,3].

3.2. The A19 Anechoic Wind Tunnel

3.2.1. General Configuration

This is a free-flow wind tunnel, this flow being located in a soundproofed enclosure. The principal features, upstream to downstream, are:

-- An admission noise suppressor.

-- A high contraction ratio converging duct, preceded by a grid for maximum reduction of turbulence, which is particularly troublesome in acoustical tests.

-- A cylindrical free flow 2 m in diameter and 5 m long. The shape of the enclosure will be that of a quarter sphere with a radius of 9.6 m. The soundproofing method will be much simpler than that of the current installation, which was found to be excessive. There will be a cement monocoque chamber resting on shock absorbers, an air gap and dihedrals on the inside.

-- A diffuser followed by a noise suppressor.

-- The air driver, which will probably consist of pumps, whose high frequency noise will be easier to damp than that of a fan.

-- A final noise suppressor.

3.2.2. Operation

The flow speed in the test duct will be 100 m/sec, which roughly corresponds to the take-off or approach speed of current airplanes.

The air feed device, consisting of tested pipes, will be analogous to that of the existing installation.

There will be no basic differences in performance of measurements between this wind tunnel and the current chamber. It might be noted that the microphone will be able to move farther away from the model (up to approximately 8.5 m). In addition, the measurement chain will be improved from a technical standpoint (presence of a minicomputer in the control room).

Fig. 19. View of the wind tunnel and local additions.

Fig. 20. Diagrams (front and overhead views).

3.3. Metrologic Laboratories of the Toulouse Study and Research Center (CERT) /8

These laboratories are connected with the Advanced National School of Aeronautics and Space (ENSAE) and also are related to ONERA.

Installations designed for acoustical metrology are under completion at the Measurement Administration (Fig. 21).

An anechoic chamber with dimensions of 10 x 5.6 x 6.3-mm (cement interfaces), and thus approximately 6 x 2 x 3 m of useful acoustical volume [sic]. The cutoff frequency will be 80 Hz. An opening will be provided for study of sound transmission by wall elements.

-- a small reverberating chamber with non-parallel walls and dimensions of approximately 5 x 4 x 2.5 m will permit acoustic power measurements on small equipment and measurement of absorption by the Sabine method.

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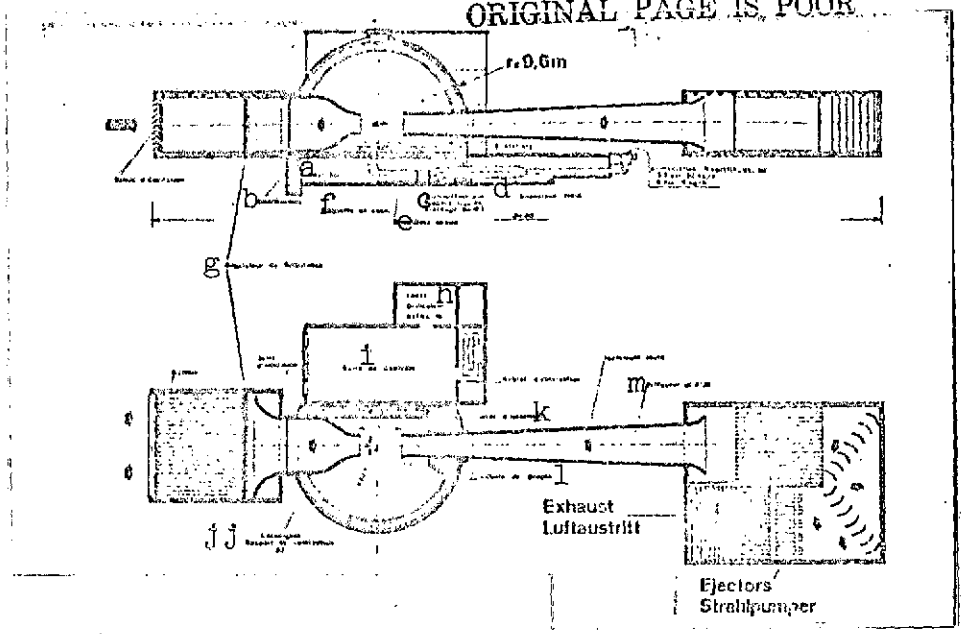

Fig. 20. A19 anechoic wind tunnel. 0.2 m. Speed 100 m/sec. Saclay Center for Testing of Propulsion Systems.

Key: a. Underground.
b. Shock absorbers.
c. Heater using liquid propane; storage 2000 liters.
d. Cold noise suppressors.
e. Hot noise suppressors.
f. Test bottom structure.
g. Turbulence regulator.
h. Local computer.
i. Control room.
j. Converging duct, contraction ratio 33.
k. Insulating joint.
l. "Dragon's teeth."
m. Diffuser.

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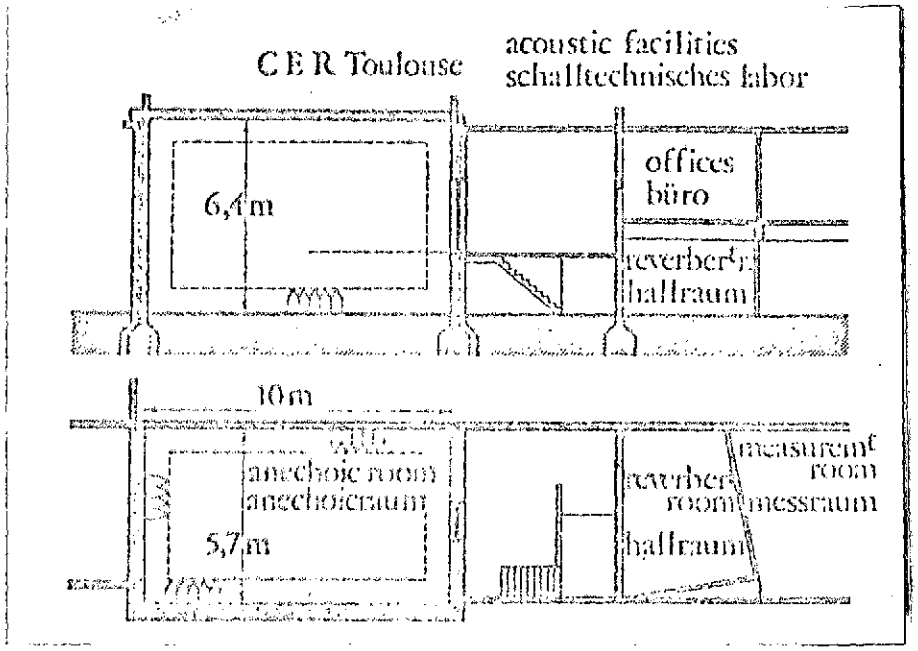

Fig. 21.

-- an intermediate space between the two rooms permitting coupling and a measurement room will complete the installation.

3.4. Outfitting of Wind Tunnels

The helicopter noise measurements performed in the large Modane wind tunnel have already been noted. Sound calibration studies are currently in progress in an ONERA subsonic wind tunnel with a guided flow 3 m in diameter having a maximum speed of 100 m/sec.

By using microphones flush with the wall it should be possible to perform at least comparative measurements of the noise produced by various profiles.

Study of the noise attenuation characteristics of a small induction wind tunnel has been performed by ONERA [6] in preparation for a more powerful installation planned for Toulouse.

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Fig. 22 shows a diagram of this small wind tunnel. The duct walls have been lined with plastic foam and a thin sheet of perforated vinyl.

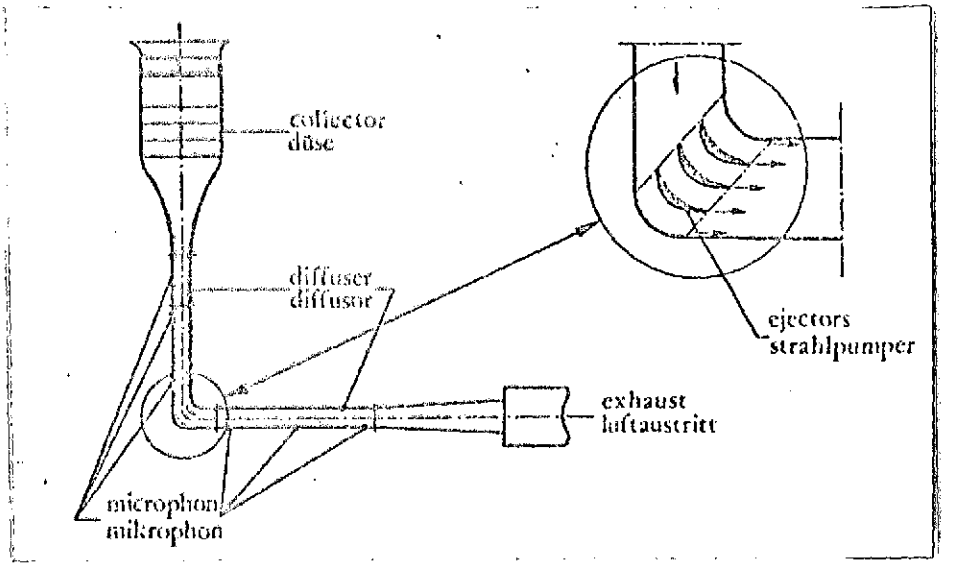

Fig. 22.

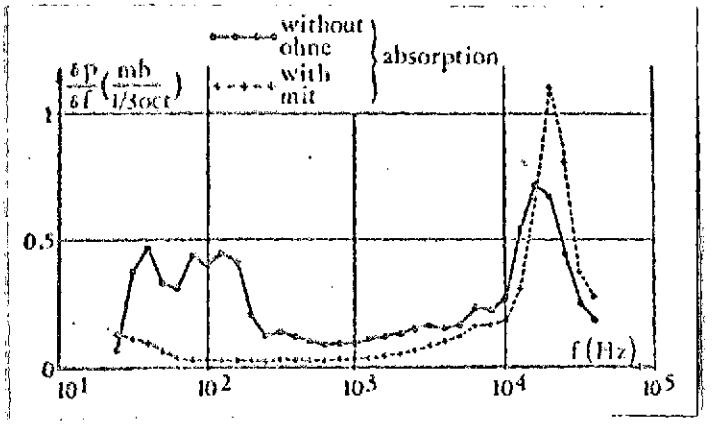

Fig. 23.

Fig. 23 shows the noise levels observed at the wall of this duct with anddwithout this lining. An appreciable decrease is observed at mean frequencies. In contrast, extreme frequencies propagated from the injectors without reflection on the walls are not absorbed. /9

Finally, a large wind tunnel is currently under construction in the ONERA complex at Toulouse-Le Fauga.

Fig. 24 gives a diagram of this wind tunnel. This is a return wind tunnel with a 4.5 x 3.5 m guided flow at transonic

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speeds whose average pressure may be brought up to [number missing in original] bars, The measurement duct is mounted on a carrier, permitting preparation for tests outside the tunnel, as in the Modane S1.

Fig. 25 shows a remote and still uncertain plan for outfitting this wind tunnel for acoustical testing, in order to perform aerodynamic noise measurements at low speeds.

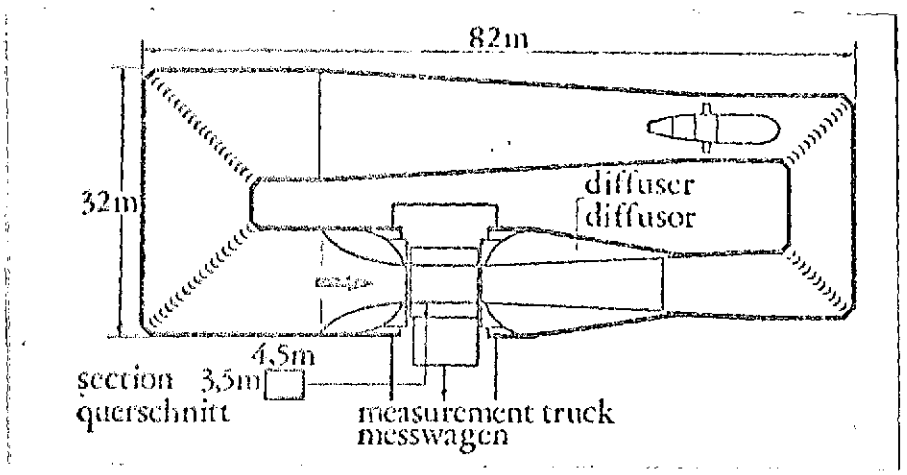

Fig. 24.

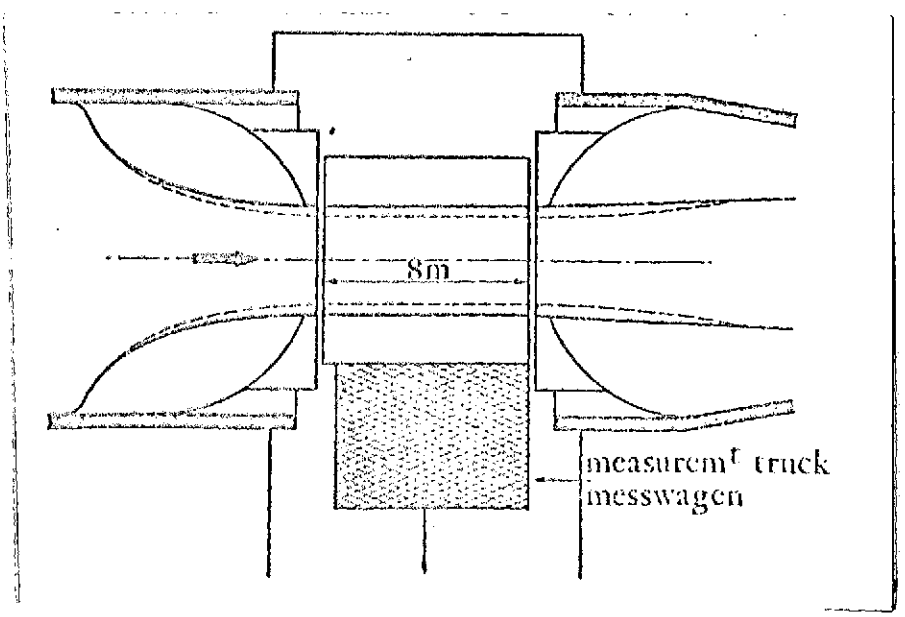

Fig. 25.

4. Conclusion

The era in which acoustical analysis of aircraft noise was limited to overall measurement of the far sound field has ended. The only way to continue to reduce aircraft noise is to determine the noise sources in flows and the radiation from these sources.

In return, research whose initial purposes were solely acoustical will provide basic knowledge of turbulence and fluid flow.

The methods being implemented and the installations planned are costly and complex; obviously, these methods are or will be available to everyone for mutual information and furthering of knowledge.